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## Comparison of Systems Formed of Moulded Pressboard Barriers and Fully Wrapped Crepe Paper Insulation in the Case Study of UHV Winding Exits

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# Comparison of Systems Formed of Moulded Pressboard Barriers and Fully Wrapped Crepe Paper Insulation in the Case Study of UHV Winding Exits

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CIGRE Working Group (A2-37) Transformers Reliability Survey reported that about %50 of major failures occur in the windings. Action taken after failure is failure location in scrapped transformers WINDINGS %65, in repaired transformers WINDING %42. Breakdowns of insulation components are one of the major problems in high voltage transformers which are caused by partial discharge (PD). One of the most important and sensitive insulation part of transformer is the insulation between the HV winding and the tank, including the HV bushings. The determination of the quality of transformer insulation, the quality of material to be used and the design play an important role and are decisive about lifetime of power transformers. Due to PD, properties of exit insulation systems deteriorate enormously. In the end, breakdown takes place and entire power system might collapse. Therefore, continuous monitoring and detection of PD is the one of the important task for electrical engineer to keep the high voltage power equipment in healthy condition. When we compare pressboard barrier system with insulation made by full wrapped crepe paper in terms of moisture and ageing; soft crepe paper absorbs more moisture. This absorbed excessive moisture is exposed to a longer drying process. Crepe paper insulation is aged due to this longer process. Particularly problematic is moisture (excessive or ppm) in transformers; it affects both solid and liquid insulation. Most of the water is in the form of dissolved water and is available to move from the oil to the crepe and solid insulation as the transformer progresses towards equilibrium. We aim to examine ageing and moisture effects on the electric breakdown strength of pressboard and crepe paper insulation under AC voltage condition. The barriers have main function to increase the dielectric strength due to divide tighter gaps. So it is possible to optimize of HV transformer lead exit system. Actually barrier system (oil gap) is using also in the windings. A barrier is a structure which is designed to stop electrons that is spreading. In case of non-uniform field oil gaps, the gaps can be divided into narrow spaces. In order to determine these spaces, designers have to use programs used FEM and special design curves. This paper will focus on the points of electrostatic stress, moisture behaviour and partial discharge.

***Keywords:*** *Pressboard barrier, crepe paper, exit insulation system, winding, moulded barriers, HV Insulation material, FEM Analysis*

## 1. Introduction

During manufacturing the water content in cellulose must be equal to or lower than %0,5 in order to ensure a long life time of a transformer. Yet, cellulose based insulation materials and components display various behaviours against heat and vacuum due to structural differences and geometrical and thickness differences in the place of use. [1]

The period from afterwards of active part drying till when the transformer is placed in the tank and vacuum impregnation is a very critical process. In the meantime, the active part may be kept in production area for a period reaching to several hours. At the same time, moisture absorbing characteristics of insulation materials may vary according to structural properties of material and usage area. [1]

Probable mistakes that can be made during the processes as drying, idle position, vacuum impregnation, conditioning and testing may lead to decades of shortening the lifetime of a transformer which is expected to have a service time more than 50 years under proper conditions.

For this purpose, paper and board, two main materials conditioned equally were compared in terms of drying behaviour, influence on transformer oil, moisture absorption/loss via some basic test methods.[2][3][4]

## 2. Basic Experimental Design Procedures and Case Study

Models of insulation structures were examined using two types of materials commonly used in exit insulation system and connection system: Crepe paper and moulded pressboard. Examination started with firstly forming two models equivalent to each other in terms of “electrostatic field intensity” via software used FEM. [1]. The systems were equalized by using same safety coefficient for different levels of voltage. A comparative study is conducted for the simulation of the systems used in lead connection. In section 2.3 Case Study; models of connection structures made of moulded pressboard barriers were examined using 3D mechanical drawing and Electrostatic calculation tools in actual project.

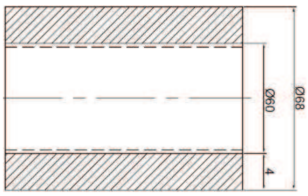



Figure 1 - Model A – Crepe Paper (CP)

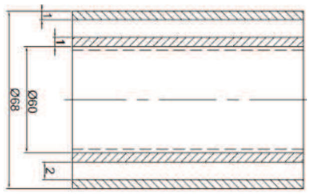



Figure 2 - Model B – Moulded Pressboard (MPB)

Model A, 1 mm and 4 mm of crepe paper (CP) insulation on aluminium tube, 50% overlapping (IEC 60554-3-3)
Model B, 1 mm moulded pressboard (MPB) and also 1 mm moulded pressboard barrier (IEC 60641-3-1)
Below studies were conducted on equal models of insulation structures in terms of electrostatic field intensity

**2.1 Electrical Experiments**
Electrical Strength and Partial Discharge Inception Voltage (PDIV)
**2.2 Chemical Experiments**
Observing Amounts of Water Content in Two Models (One week, dried at 105°C, <0,01 mbar)
**2.3 Case Study**
Connection System with Pressboard Barriers for 800 kV HV windings

### 2.1 Electrical Experiments

Under operating conditions, long term applications of operating voltage in combination with other factors (temperature, mechanical stress, ionization radiation etc.) reduces the electric strength of insulation material and ultimately takes it out of service due to aging. [5]

The insulation in transformers can be classified as major and minor insulation. The major insulation involves insulation between the windings, the windings and the core, high voltage LEADS and ground while minor insulation is the insulation within the windings, for instance: interturn and interdisc insulation. [6] A decreased electric field intensity at the initial stage of design is aimed for HV and UHV systems. The influence of the geometries is huge in terms of arranging and smoothing the electric field which can be reduced to expected levels by adjusting geometries and distances.

A reduced maximum dielectric stress is usually not enough for a good dielectric performance. Volt – time characteristic and partial discharge inception level of insulation material, waveform of the voltage applied, electrode shape and surface conditions, impurities, moisture etc. should also be taken into consideration. [6]

Decreasing regional high stress location and bigger overlaps for better creepage strength, production without voids, uniform electrical fields are some of basic points of insulation design. [7] [8] Positioning of insulation in known geometries will help in better optimization and design of safer systems. Optimized designs can be adapted during the design stage by considering the operating and production conditions of the insulation materials (pre-conditioning, processes, drying, oil absorption etc.).

Two different models of insulation structures are compared in point of strength of oil ducts in below simulation by calculating the electric field between a spherical electrode and a cylindrical electrode details of which are given above. The two models of insulation structures examined are moulded pressboard barrier system and thick insulation made of crepe paper.

Comparison curves and results;

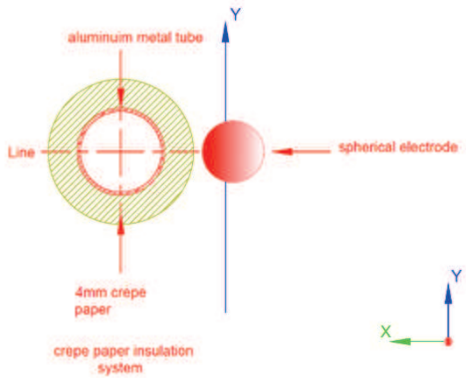



Figure 3 - Model A - Geometry of Crepe Paper Insulation (Wrapped)

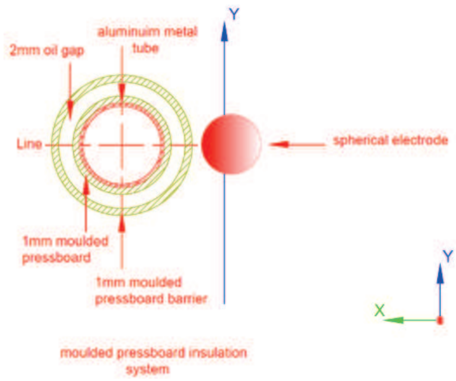



Figure 4 - Model B - Geometry of Moulded Pressboard Barrier

Systems were equalized by keeping the same safety factor in electric fields studies at similar voltage levels.
The studies are made with the curves of partial discharge inception voltage versus width of oil duct for degassed oil.

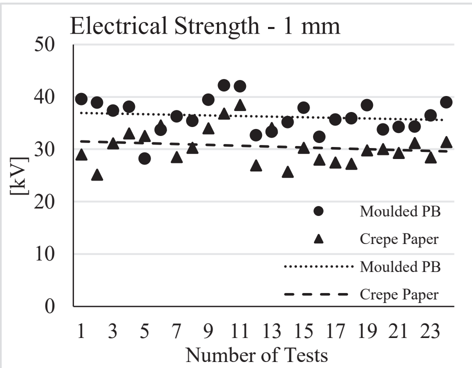



Figure 5 – Electrical Strength of 1 mm Insulation

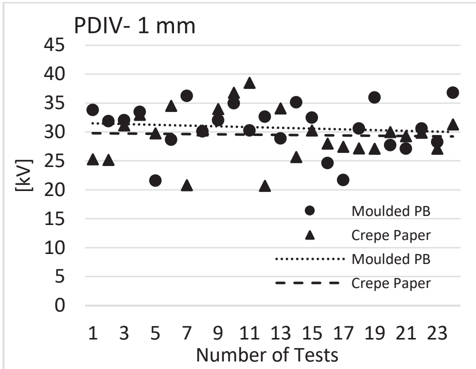



Figure 6 – PDIV of 1 mm Insulation

1 mm crepe paper insulation wrapped on aluminium tube, 50% overlapping (IEC 60554-3-3)
1 mm Moulded Pressboard (MPB) on aluminium tube (IEC 60641-3-1)
Below studies were conducted on equal models of insulation structures in terms of electrostatic field intensity

Comparison of the models made of 1 mm crepe paper insulation and 1 mm Mouldable Pressboard from the point of Electrical Strength and Partial Discharge Inception Voltages are given above. Partial Discharge Inception Voltages seem similar as per trend lines. Nevertheless Mouldable Pressboard produces better results compared to crepe paper in terms of Electrical Strength. [9]

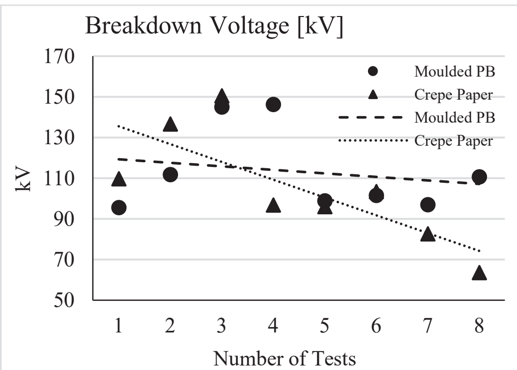



Figure 7- Breakdown Voltage of Insulation Systems (Model A and B)

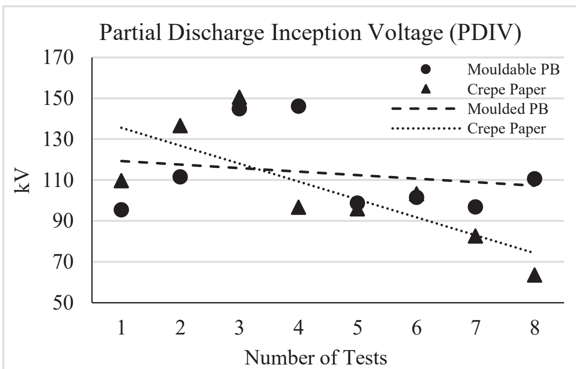



Figure 8 - PDIV of Insulation Systems (Model A and B)

Although crepe paper system is the same as the barrier system with Moulded Pressboard in regards to oil duct strength in the simulation results, the barrier system with Moulded Pressboard is stable when the test results are compared.

## 2.2 Chemical Experiments

**Observing Amounts of Water Content in Two Models (Crepe Paper and Mouldable PB)**

(1week, 168 h, under 0,01 mbar, at 105°C)

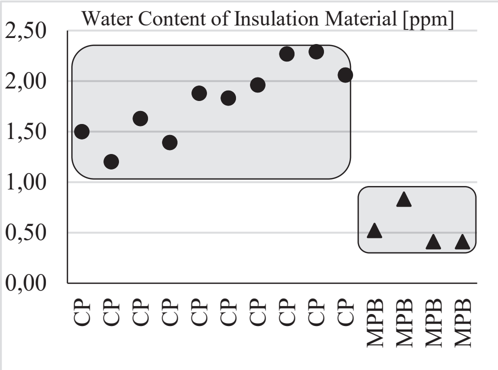



Figure 9 – Water Content of Insulation Material

Water content tests were conducted on two models dried for 1 week at 105°C under 0, 01 mbar in same furnace.

Moulded pressboard (MPB) reached to required values but it was concluded that the water content of crepe paper was not at acceptable level. A water content 1-2 % was measured on crepe paper.

Due to thickness of the crepe paper, the drying is not practicable. The water content remained has a significant effect on ageing of material. [10][11][12]

The main factors in the aging of insulating winding paper and pressboard in a transformers are the presence of oxygen, temperature and humidity.[13][14][15][16]

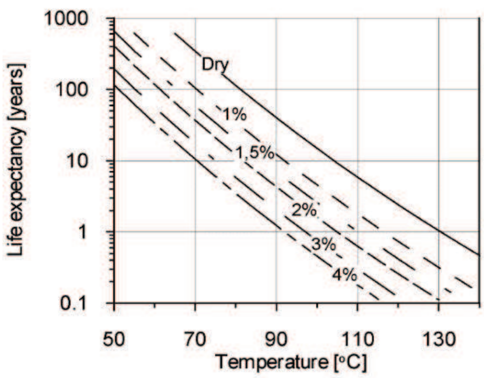



Figure 10. Expected life for solid insulation and its dependence upon moisture and temperature

Ageing of cellulosic insulation in transformers is caused by oxidation, carboxylic acids, and water, which enhance the catalytic efficiency of the acids by promoting their dissociation. [17][18][19][20]

## 2.3 Case Study:

**Connection System with Pressboard Barriers for 800 kV HV windings**

When the power of the transformer increases, winding is distributed to the two limbs of the core. Connecting parallel windings in these two limbs at high voltage can create a problem that needs to be solved. Preferring thick crepe insulation leads to drying difficulties and assembly limitations. Long drying processes will cause aging of the materials as well as drying deficiencies cause problems in the tests. Above mentioned defects caused by thick crepe-paper insulation ensure that the pressboard barrier systems should be preferred.

When the thick crepe paper insulation is not alone enough pressboard barriers should also be placed on them. The electrical connections are made via conductive copper wrapped with crepe paper. When these connections are considered for the assembly of crepe insulation and wrapping barriers, the assembly takes a long handling process. Each handling allows different dielectric materials to be carried. Different dielectrics may adversely affect the system. In addition, connection systems are fixed by pressboard clamps and laths. Connection systems made of thick crepe paper insulation may not be preferred due to short creepage distance on fixing part located on core which connects clamp to pressboard barriers. These systems, which are fixed in itself can cause vibration during the dynamic short circuit tests. Pressboard Barrier systems mechanically extend the creepage distance. Therefore, it is safe to make a connection to core clamping with clamps and lath systems. The vibration becomes less during the short circuit tests thanks to more sections of fixing.

As mentioned above, at high voltages such as 800 kV and 1200 kV and high powers, when a pressboard barrier system is used instead of insulation made with thick crepe paper, the drying process will be optimized and moisture will not damage insulation material during drying process thus insulation material will age less.

The connection systems are designed mechanically and electrically during the design phase. Barrier systems help designers create solutions that are always safe, with fewer risk points. The connections become very safe and easy at 800kV level.

800 kV Pressboard barrier connection system experience shown below

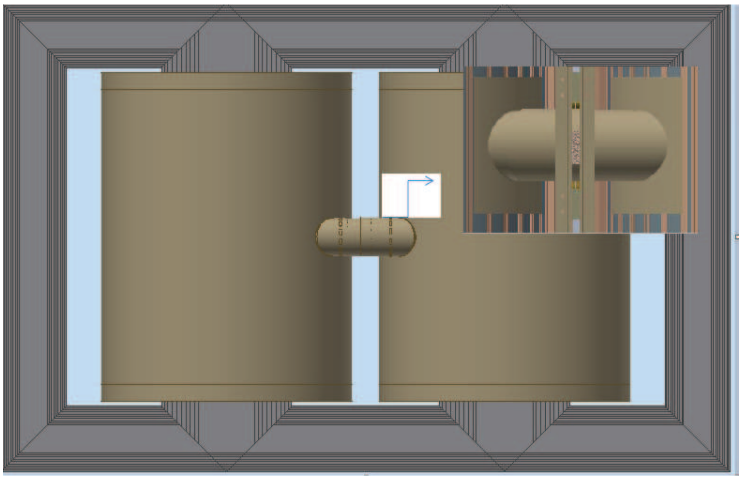


Figure 11: Sketch of  Connection location

At 800 kV voltage, the winding is connected to the exit side. The system is analysed mechanically and electrically for transition from a parallel winding to another. Considering the gap between the flanged tubes, winding cylinders and the limited winding distance, design is made with appropriate transition and overlapping distances. The use of a system of barriers in this design allows us to produce solutions that provide ease of assembly. The 2D and 3D electric field analysis enables us to determine that the system is safe.

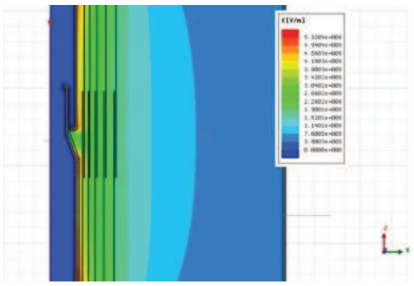


Figure 12

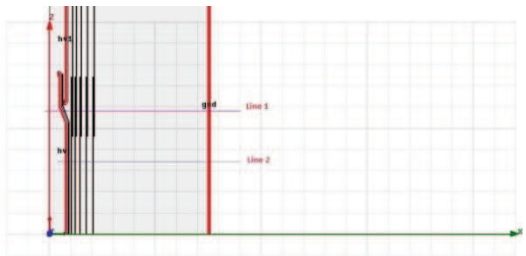


Figure 13

Each oil duct is analysed for critical points. The system is optimized for high electrostatic stress density. Reliable design is created step by step in each iteration. The Pressboard barriers electrostatic field analysis of which are shown above allow easy mechanical couplings with overlaps. Mechanical assembly on this side is designed without any problem on nested oil channels. After the electrostatic controls, the system is analyzed by performing a mechanical assembly simulation.

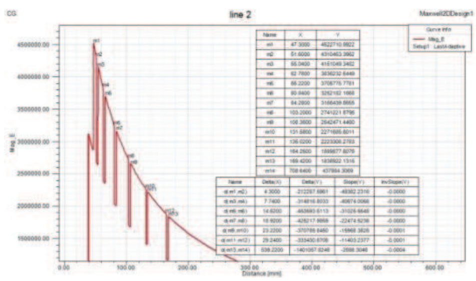


Figure 14. 2D Electrical field calculation results

3D Electrical field calculation and results

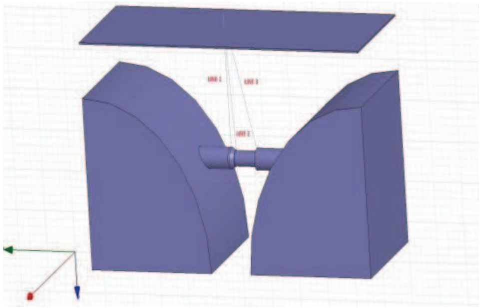


Figure 15

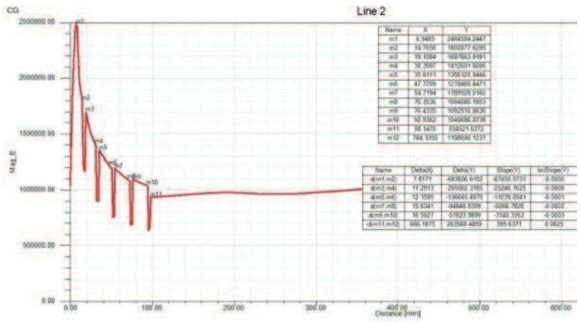
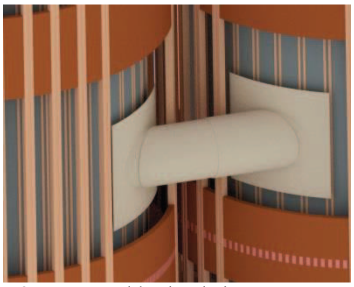
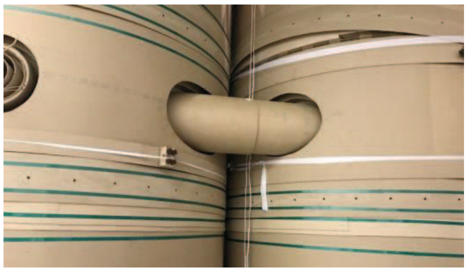



Figure 16

3D mechanical simulations allow us to see the difficulties to be faced in the assembly phase and provide early vision in terms of tolerances.



3-D Assembly simulation



Assembly

Figure 17 Assembly Simulation

Both the mechanical and Electrical precautions apply to defined critical point. Designed geometries passes all mechanical and electrical test successfully.

**Conclusion:**

This experiment researches on two insulation techniques, moulded pressboard and crepe paper insulation, through comparison of degree of polymerisation (DP), oil contamination and water content values that are followed by PD inception voltage, breakdown voltage tests on equivalent electrode system and design experiments for HV windings connections which are commonly used in HV transformers.

In addition, the 800 kV link connection system in the application project was designed mechanically and electrostatically to see the differences between these two insulation techniques in practice.

Simulation studies have shown that the thick crepe insulation causes mechanical limitation of assembly. If the barrier system is used at the same area, it provides design facilities as well as intertwining and mobility as it allows an electrically safer connection on different connection points, it is experienced in the application project where better results are obtained in short circuit tests.

The Link connection system made of thin oil ducts make the system more stable as well as increasing the efficiency of the pre-conditioning process compared to thick crepe paper. Drying and oil impregnation processes are easier on Moulded Pressboard barriers thanks to thin layers.

## REFERENCES

[1] S.Yurekten, E.Öztürk, F.Erenler,Pressboard Barriers Versus Full Wrapped Crepe Paper in Exit Insulation System for HV Power Transformers, 4th International Colloquium "Transformer Research and Asset Management ,Pula - Croatia , 10-12 May 2017

[2] S.Yurekten, E.Öztürk, F.Erenler, Insulation components for HV Power Transformers, Travek X-th International Scentific and Technical Conference,Power and Distributive Transformers,Reactors,Systems of Diagnostics, Moscow, 21-22 June 2011

[3] F.Erenler, S.Yurekten, The Quality Aspects of Solid Insulation in Power Transformers and Reactors, In association with CIGRE, 5.International Conference on Large Power Transformers-Modern Trends in Application, Installation, Operation & Maintenance, New Delhi, 22-25 Jan.2013

[4] S.Yurekten, E.Öztürk, F.Erenler, Modern Trends in Application of Insulation Systems for Power Transformers, 11.International Conference Trafosem 2011, Indian Transformer Manufacturers Association, NewDelhi 21-22 Nov. 2011

[5] Vasily Y. Ushakov, Insulation of High-Voltage Equipment, Fırst Edition, Springer Verlag Berlin Heidelberg, 2004

[6] S.V. Kulkarni, S.A. Khaparde, Transformer Engineering: Design, Technology, and Diagnostics, Second Edition, CRC press.

[7] S. Yurekten, Technical Assesment of Lead Exit and Design Process, Travek VII International Scientific and Technical Conference, Large Power Transformers and Diagnostic Systems, Moscow 22-23 June 2010

[8] E. Öztürk, Exit Insulation Systems (EIS) &Middle Exit Systems, 12.International Conference on Transformer Trafosem 2013, Innovative Quest for transformer Technology for Efficient and reliable Power, Bengaluru 15.nov.2013

[9] H.-Z. Ding, Z. D. Wang, P. Jarman, Ageing and Moisture Effects on the AC Electrical Strength of Transformerboard, 2007 International Conference on Solid Dielectrics, Winchester, UK, July 8-13, 2007

[10] Pankaj Shukla, Y.R. Sood, R.K. Jarial, Experimental Evaluation of Water Content In Transformer Oil, International Journal of Innovative Research in Science, Engineering andTechnology, Vol. 2, Issue 1, Janauary 2013

[11] Andras Csernatony-Hoffer, Experimental Results with Vacuum Drying of Thick Soft Paper Insulation, IEEE Transactions on Electrical Insulation, Vol. EI-3, No. 4, November 1968

[12] Brian Sparling, Jacques Aubin, Assessing Water Content in Insulating Paper of Power Transformers

[13] Lars E. Lundgaard, Walter Hansen, Dag Linhjell, Terence J. Painter, Ageing of Oil Impregnated Paper in Power Transformers, IEEE Transactions on power Delivery, Vol.19, No.1, January 2004

[14] Loai S. Nasrat, Nesrine Kassem, Nadia Shukry, Aging Effect on Characteristics of Oil Impregnated Insulation Paper for Power Transformers ENG_2013010817240975

[15] Lars E Lundgaard, Dave Allan, Ivanka Atanasova -Höhlein, Regine Clavreul, Mats O.Dahlund, Hans Peter Gasser, Richard Heywood, Christoph Krause, Marie-Claude Lessard, Tapan Kumar Saha, Victor Sokolov, Alfonso de Pablo, CIGRE WG D1.53, Ageing of Impregnated Cellulose for Transformers

[16] H.P. Gasser, J. Huser, C. Krause, V. Dahinden, A.M. Emsley, Determining The Ageing Parameters of Cellulosic Insulation in A Transformer

[17] J. Gielniak, A. Graczkowski, S. Gubanski, H. Moranda, H. Moscicka-Grzesiak, K. Walczak, Influence of Thermal Ageing on Dielectric Response of Oil-Paper Insulation, Materials Science-Poland, Vol. 27, No. 4/2, 2009

[18] Mohamad Ghaffarian Niasar, Mechanisms of Electrical Ageing of Oilimpregnated, Paper Due to Partial Discharge, Doctoral Thesis in Electrical Systems, KTH Electrical Engineering, Stockholm, Sweden, 2015

[19] J. Dai, Z. D. Wang, P. Jarman, 13 - Moisture and Aging Effect on the Creepage Discharge Characteristics at the Oil/Transformerboard Interface under Divergent Field, 2008 Annual Report Conference on Electrical Insulation Dielectric Phenomena

[20] Laurentiu Badicu, Petru V. Notingher, Laurentiu Dumitran, Gabriel TANASESCU, Dorin Popa, and Gheorghe Batır, Thermal Ageing of Oil Impregnated Paper for Power Transformers Insulation Systems